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Heterosis studies for earliness, fruit yield and yield attributing traits in bell pepper

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The present investigation was envisaged to gather information about the potential and characteristics of the experimental material of bell pepper at the Vegetable Research Block, Department of Vegetable Science, College of Forestry and Hill Agriculture, Gobind Ballabh Pant University of Agriculture and Technology, Hill Campus, Ranichauri (Tehri Garhwal), Uttarakhand (India) during rainy-autumn season, 2009 to 2010. The combined analysis of 6 × 6 diallel revealed significant variation among genotypes in parents, F_1 crosses and parents versus F_1 crosses for all the studied characters except for pericarp thickness and number of branches for parents, indicating that the used parents in diallel mating design and their crosses were genetically diverse. A wide range of heterosis over better parent and standard check was observed in F1 generation for marketable fruit yield and its attributing traits. The F_1 crosses PRC-1 × California Wonder and California Wonder × SSP had revealed the highest significant desirable heterosis both over better parent and standard check (California Wonder) for early maturity. The F_1 crosses (Rani Sel-1 × SSP, Rani Sel-1 × Sel-12-2-1, SSP × SP-316 and PRC-1 × California Wonder) showed appreciable heterosis over better parent and standard checks for marketable fruit yield per plant and quality traits in bell pepper. The high heterotic response as observed in these hybrids further supported by the predominant role of non-additive component in the inheritance of the characters studies. These cross combination could be exploited in heterosis breeding programme.

Key words: Heterosis, bell pepper, capsicum, hybrid breeding, horticultural traits, fruit yield.

INTRODUCTION

Bell pepper (*Capsicum annuum* L. var. *grossum* Sendt.) commonly known as sweet pepper or capsicum, holds a very coveted position as a leading off-season vegetable in Himachal Pradesh, generating cash revenues to the farmers by selling the produce in the neighbouring states and metropolitan cities. In recent years, its demand has increased tremendously with the emergence of pizza industry (Sood et al., 2011). Besides, it also has medicinal properties and hence, recommended for the treatment of dropsy, colic toothache and cholera (Pairce, 1987). Green bell pepper (*C. annuum* L.) is an excellent source of ascorbic acid and a fair source of provitamin A carotenoids (Haytowitz and Matthews, 1984). In addition, peppers are rich in flavonoids (Lee et al., 1995) and other phytochemicals (Duke, 1992). Presently, it is extensively grown in Himachal Pradesh, Uttarakhand, Jammu and

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Kashmir, Arunachal Pradesh and Darjeeling and in some parts of West Bengal during summer months and as an autumn crop in Maharashtra, Karnataka, Tamil Nadu and Bihar. Bell pepper transported to distant market in the plains bringing handsome returns to the small and marginal farmers. In spite of its importance, a few varieties are grown commercially. California Wonder an old introduction being grown extensively throughout the country. In recent times, the production scenario of capsicum has changed with the increasing popularity of hybrids cultivated on commercial scale. Hybrids not only led to a boom in the productivity but also helped improving the quality of the produce. Sweet pepper offers much scope of improvement through heterosis breeding method (Sood and Kumar, 2010b). The systematic approach for developing F_1 hybrids in any crop depends primarily on magnitude of desirable heterosis. It offers much scope for improvement through heterosis breeding among genetically diverse genotypes, which can be further utilized for the development of desirable recombinants.

As the required goals of increasing productivity in the quickest possible time can be achieved by utilizing heterosis breeding, which is feasible in this crop (Joshi and Singh, 1980); information on the magnitude of heterosis in different cross combination is a basic requisite to assess for identifying crosses that exhibit high amount of exploitable heterosis. The present investigation describes the extent and nature of heterosis in hybrids for earliness, fruit yield and its attributes.

MATERIALS AND METHODS

The present investigation was envisaged to gather information about the potential and characteristics of the experimental material of bell pepper at the Vegetable Research Block, Department of Vegetable Science, College of Forestry and Hill Agriculture, Gobind Ballabh Pant University of Agriculture and Technology, Hill Campus, Ranichauri (Tehri Garhwal), Uttarakhand during rainy-autumn season, 2009 to 2010.

Experimental site

Location

The experimental site is located at about 10 km away from Chamba (on Rishikesh-Gangotri Road) at an altitude about 2000 m above mean sea level. Geographic position of the experimental site lies between 30° 15' N latitude and 78° 30' E longitude under mid hill zone of Uttarakhand, India.

Climate

The climate is humid temperate. The mean monthly minimum and maximum temperature varied between 6.0 to 16.6 and 17.5 to 23.7°C, respectively during the cropping season. The experimental site experienced average rainfall of 117.84 cm annually, out of which about 61.0% is received during monsoon period. Monsoon arrives in the second fortnight of June and ends in September. The summer is mild and winter is very severe. Light to heavy snow fall is a regular feature of this area during December to February.

Soil

The soil of the experimental block was silt clay to silt loam in texture, low in available nitrogen (210.0 to 218.5 kg ha^{-1}) and phosphorus (11.5 to 13.5 kg ha^{-1}) and rich in potash (408.0 to 418.0 kg ha^{-1}). The electrical conductivity as measured in 1:2 soil water ratio was 0.5 to 0.7 dsm^{-1}. The depth of the soil extends up to 2.0 m.

Experimental materials

The experimental materials comprised of six genetically diverse bell pepper genotypes (parents) and their fifteen F_1 crosses. The main characteristics of the six parental lines are given in Table 1.

Mating design and material development

The F_1 crosses were made manually using a standard procedure of hand emasculation and pollination in a diallel mating design (without reciprocals) during summer- rainy season, 2008 to 2009. The sufficient F_1 cross seed was obtained for evaluation in the next summer- rainy season, 2009 to 2010. Selfed seeds of the parents were also obtained during the same season.

Nursery sowing

The seeds were sown on April 8, 2009 in raised nursery beds under polyhouse at vegetable research block, Hill Campus, Ranichauri. Healthy and disease free seedling of twenty one genotypes (6 parents and 15 F_1 crosses) were transplanted on May 25, 2009 (Table 3).

Experimental design and layout plan

The final trial was laid out on May 25, 2009 comprising of six parents and fifteen F_1 crosses were sown in the nursery and transplanted in Randomized Block Design (RBD) with three replications in plot size of 2.0 × 2.0 m. The plants were spaced at 60 cm between row to row and 45 cm plant to plant. The experimental field was prepared by ploughing twice with power tiller up to a depth of 20 cm followed by leveling. The farm yard manure (20 t ha^{-1}) was mixed in the soil at the time of field preparation with first ploughing. The chemical fertilizer (70 kg N, 80 kg P_2O_5 and 80 kg K_2O) were applied as basal dose at the time of field preparation. One third of N, full dose of P_2O_5 and K_2O is applied at the time of final field preparation. Remaining two third N was top dressed in two equal amounts and added after 30 and 45 days of transplanting, respectively. The observations were recorded on five randomly selected plants for days to 50% flowering, days to first harvest, number of pickings, fruit weight (g), fruit diameter (cm), fruit length (cm), fruit girth (cm), number of fruit per plant, number of lobs per fruit, pedicel length (cm), pericarp thickness (cm), number of branches per plant, plant height (cm) and marketable fruit yield per plant.

Ascorbic acid content (mg per 100 g fresh weight) from the crushed fruit sample was estimated by the method as described by Ranganna (1986). California Wonder was used as a standard check for estimation of commercial heterosis.

Table 1. Distinguished morphological features of bell pepper genotypes.

S/N	Parents	Source	Fruit color at immature stage	Fruit color at mature stage	No. of lobes	Fruit shape
1	PRC-1	Department of Vegetable Science, Hill Campus, Ranichauri	Dark green	Orange yellow	3.00	Rectangular
2	California Wonder (CW)	IARI, Regional station, Katrain	Medium green	Red	4.00	Bell shape
3	Rani Sel-1	Department of Vegetable Science, Hill Campus, Ranichauri	Dark green	Red	3.00	Bell shape
4	SSP	Department of Vegetable Science, Hill Campus, Ranichauri	Medium green	Red	3.00	Rectangular
5	Sel-12-2-1	Department of Vegetable Science, UHF, Solan	Dark green	Red	3.00	Triangular
6	SP-613	Department of Vegetable Science, UHF, Solan	Medium green	Red	3.00	Triangular pointed

Statistical analysis

The mean values of different genotypes for various characters were statistically analyzed using SPAR-1 programme of Doshi and Gupta (1981). SPAR I (developed by Indian Agricultural Statistical Research Institute, New Delhi, India) software was used for statistical analysis. Heterosis was computed by using computer software programme Windowstat 8.0.

RESULTS

The combined analysis of variance (Table 2) revealed that, significant variation among genotypes in parents, F_1 crosses and parents versus F_1 crosses for all the studied characters except for pericarp thickness and number of branches for parents, indicating that the parents used in diallel mating design and their crosses were genetically diverse. A wide range of heterosis over better parent and standard check was observed in F_1 generation for most of the studied traits. The magnitudes of heterobeltiosis for days to 50% flowering were ranged from -12.86 to 5.83 and -13.33 to 5.58% over better parent and standard check, respectively. Twelve F_1 crosses exhibited negative heterosis, of which eleven were found to have significant desirable negative heterosis over better parent for days to 50% flowering. The highest negative heterobeltiosis was recorded in cross combinations namely, California Wonder × SSP (-12.86%), SSP × Sel-12-2-1 (-10.74%) and California Wonder × SP-316 (-9.67). Among 15 F_1 crosses, only 11 exhibited significant negative heterosis and two crosses revealed significant positive heterosis over the standard check. The highest desirable significant heterosis was found in F_1 crosses PRC-1 × California Wonder (-13.33%) and PRC-1 × SP316 (-13.33%) over standard check, respectively for days to 50% flowering.

The magnitudes of heterosis for days to first harvest in F1 crosses were ranged from -16.14 to 2.15% over better parent. Only eight F1 crosses showed desirable significant heterobeltiosis and remaining crosses exhibited non desirable heterosis. The highest desirable heterobeltiosis was found in the cross combinations PRC-1 × SP316 (-16.1%) followed by SSP × SP316 (-13.00%) and California Wonder × SSP (-11.87%), respectively. Among 15 F1 crosses, only seven exhibited significant negative heterosis over standard check. The F_1 crosses California Wonder × SSP and PRC-1 × SSP exhibited highest significant heterosis for days to first harvest in desirable direction to the tune of -11.87% each over standard check. The top three hybrids for days to first harvest over standard check were California Wonder × SSP (-11.87%), PRC-1 × SSP (-11.87%) and PRC-1 × California Wonder (-10.04%) and PRC-1 × SP-316 (-16.14%), SSP × SP-316 (-13.00%) and California Wonder × SSP (-11.87%) for over better parent reported. The estimates of percent heterosis for number of pickings in F1 crosses were ranged from –20.00 to 44.44 and 8.79 to 31.43% over better parent and standard check, respectively. Eleven F1 crosses had exhibited significant positive heterobeltiosis for this trait. The maximum heterosis to the extent of 44.44% was recorded in the cross PRC-1 × Rani Sel-1 followed by Rani Sel-1 × SP-316 (41.66%) over better parent. The highest economic heterosis was recorded in cross Rani Sel-1 × SP-316 to the tune of 31.43% over standard check.

The top three hybrids for number of pickings over standard check were Rani Sel-1 × SP-316 (31.43%), PRC-1 × California Wonder (29.93%) and PRC-1 × Rani Sel-1(24.93%) and PRC-1 × Rani Sel-1 (44.44%), Rani

Table 2. Analysis of variance for combined analysis for different horticultural traits in bell pepper.

SV traits	D. F.	Days to 50% flowering	Days to first harvest	No. of picking	Fruit weight (g)	Fruit diameter (cm)	Fruit length (cm)	Fruit girth (cm)	No. of fruits/ plant	No. of lobs/ fruit	Pedicel length (cm)	Pericarp thickness (cm)	No. of branches /plant	Plant height (cm)	Ascorbic acid content (mg/100 g)	Market-able fruit yield/ plant
P	5	12.90**	69.78**	2.93**	530.76**	0.79**	5.64**	3.08**	23.84**	1.12**	0.81**	0.35	0.25	206.78**	378.31**	52457.47**
$F_{1's}$	15	17.98**	60.40**	3.39**	77.28**	1.24**	7.48**	6.53**	12.81**	0.19	0.60**	1.65**	0.49**	389.6**	940.68**	167673.81**
P*Vs* $F_{1's}$	1	38.13**	53.15**	0.16	811.76**	0.05	12.38**	7.23**	91.13**	0.65**	0.84**	2.68**	0.13	510.56**	717.91**	840940.93**
Rep	2	0.06	2.68	3.47**	5.07	0.0011	0.62	0.81	0.51	0.09	0.00	0.17	0.88**	30.6**	102.70	2823.93
Error	40	0.73	2.24	0.41	12.52	0.08	0.55	0.91	3.70	0.11	0.18	0.21	0.16	10.7	58.42	1957.39

** Significant at 1%, * Significant at 5%.

Sel-1 × SP-316 (41.66%) and California Wonder × SSP (27.22%) over better parent. The magnitude of heterosis for fruit weight was ranged from -20.96 to 102.73% over better parent and -31.38 to 49.50% over standard check, respectively. Ten F1 crosses were found with heterobeltiosis effects for fruit weight in F1 crosses over superior parent. The cross combination Rani Sel-1 × Sel-12-2-1 (102.73%) followed by PRC-1 × Sel-12-2-1 (96.94%) had exhibited highest significant heterobeltiosis. Nine F1 crosses out of fifteen were found with significant positive heterosis over standard check. The highest economic heterosis was recorded in cross combination PRC-1 × Rani Sel-1 (49.50%) over standard check. The top three hybrids recorded with highest significant desirable heterosis for fruit weight over better parent were Rani Sel-1 × Sel-12-2-1 (102.73%), PRC-1 × Sel-12-2-1 (97.00%) and SSP × Sel-12-2-1 (83.58%) and PRC-1 × Rani Sel-1 (49.50%), California Wonder × SSP (39.42%) and Rani sel-1 × Sel-12-2-1 (34.49%) over standard check. The magnitude of heterosis for fruit diameter was ranged from -7.82 to 30.64% better parent and -13.59 to 17.81% over standard check, respectively. Seven F1 crosses were found with positive significant heterosis for fruit diameter (cm) over superior parent. The cross combination Rani Sel-1 × Sel-12-2-1 (30.64%) followed by PRC-1 × Sel-12-2-1 (28.58%) had exhibited the highest significant positive heterobeltiosis. Out of fifteen, seven F1 crosses were found with significant positive heterosis over standard check. The highest economic heterosis was recorded in cross combination Sel-12-2-1 × SP-316 (17.81%) over standard check. The top ranking hybrids for fruit diameter were Rani Sel-1 × Sel-12-2-1 (30.64%), PRC-1 × Sel-12-2-1 (28.58%) and SSP × Sel-12-2-1 (22.38%) over better parent and Sel-12-2-1 × SP-316 (17.81%), PRC-1 × Rani Sel-1 (16.12%) and California Wonder × SSP (14.80%) over standard check, respectively (Table 5).

The magnitudes of heterosis for fruit length were ranged from -3.96 to 40.76 and -3.99 to 61.18% over better parent and standard check, respectively. Ten F_1 crosses were found with positive significant heterosis for fruit length over superior parent. The cross combination SSP × SP-316 (40.76%) followed by Sel-12-2-1 × SP-316 (36.74%) had exhibited the highest significant positive heterobeltiosis. Among fifteen, eleven F1 crosses were found with significant positive heterosis over standard check. The highest economic heterosis to the extent of 61.18% was recorded in cross combination SSP × SP-316 over standard check. The three top ranking hybrids for fruit length were SSP × SP-316 (40.76%), Sel-12-2-1 × SP-316 (36.74%) and California Wonder × Sel-12-2-1 (34.17%), over better parent and SSP × SP-316 (61.18%), PRC-1 × SP-316 (52.54%), PRC-1 × Rani sel-1 (29.51%) over standard check. The magnitudes of heterosis for fruit girth were ranged from -8.74 to 25.71 and -11.66 to 17.56% over better parent and standard check, respectively. Seven crosses were found with positive significant heterosis for fruit girth over superior parent. The cross combination SSP × Sel-12-2-1 (25.71%) followed by PRC-1 × Sel-12-2-1 (24.28%) had exhibited highest significant positive heterobeltiosis. Out of fifteen, four F_1 crosses were found with significant positive heterosis over standard check, the highest being in cross combination Rani Sel-1 × SSP (17.56%) over standard check.

The top three hybrids for fruit girth over better parent were SSP × Sel-12-2-1 (25.71%), PRC-1 × Sel-12-2-1 (24.28%), Rani Sel-1 × Sel-12-2-1 (21.90%), and Rani Sel-1 × SSP (17.56%), PRC-1 × SP-316 (11.245) and SSP × Sel-12-2-1 (9.82%) over standard check, respectively. The estimates of percent heterosis for number of fruit per plant in F1 crosses were ranged from - 10.10 to 156.61 and 43.76 to 155.98% over better parent and standard check, respectively (Table 4). The

Table 3. Mean performance of parents and F_1 crosses of bell pepper (*Capsicum annuum* L.) genotypes for different horticulture traits.

S/N	Genotype	Days to 50% flowering	Days to first harvest	Number of picking	Fruit weight (g)	Fruit diameter (cm)	Fruit length (cm)	Fruit girth (cm)
1	PRC-1	35.33	64.00	6.33	74.53	5.85	10.93	17.59
2	California wonder	40.00	73.00	6.66	67.33	5.53	9.41	17.14
3	Rani Sel.1	39.00	67.66	6.00	77.16	5.89	11.98	17.25
4	SSP	39.00	70.00	8.66	79.35	5.94	10.78	17.71
5	Se1.12-2-1	40.33	77.33	7.66	44.66	4.67	8.17	14.97
6	SP-316	41.33	74.33	6.66	58.45	5.08	11.13	16.56
7	California Wonder × PRC-1	42.33	71.66	7.00	71.33	5.10	11.18	16.38
8	California Wonder × SSP	35.00	64.33	6.33	93.87	6.36	10.32	19.06
9	California Wonder × Sel-12-2-1	37.66	75.00	6.08	58.73	4.78	10.96	15.73
10	PRC-1 × California Wonder	34.66	65.66	8.66	78.33	5.40	10.47	16.86
11	PRC-1 × Rani Sel-1	35.66	67.33	8.33	100.66	6.43	12.20	19.97
12	PRC-1 × SSP	35.00	64.33	7.66	73.66	6.33	10.95	16.87
13	PRC-1 × Sel-12-2-1	39.66	68.66	7.66	88.41	6.01	10.38	18.61
14	PRC-1 × SP-316	34.66	62.33	5.66	65.33	4.80	14.37	17.38
15	Rani Sel-1 × SSP	37.00	71.33	7.66	75.54	6.09	11.77	20.15
16	Rani Sel-1 × Sel-12-2-1	39.33	69.00	7.39	50.55	6.11	10.17	18.25
17	Rani Sel-1 × SP-316	38.33	72.33	8.76	60.06	4.82	11.75	16.76
18	SSP × Sel-12-2-1	36.00	70.00	7.33	82.00	5.72	10.83	18.82
19	SSP × SP-316	37.33	64.66	6.66	86.61	5.58	25.18	17.46
20	(Sel Sel-12-2-1 × SP-316	41.66	79.00	6.10	51.62	4.55	11.17	16.94
21	California Wonder × SP-316	37.33	69.66	5.33	46.20	5.36	9.04	15.14
	SE±	0.69	1.22	0.52	2.88	0.23	0.60	0.77
	CD at 1%	1.40	2.47	1.05	5.83	0.47	1.22	1.57
	CD at 5%	1.88	3.31	1.41	7.81	1.27	1.64	2.10

S/N	Genotype	Number of fruits/ plant	Number of lobs/ fruit	Pedicel length (cm)	Pericarp thickness (cm)	Number of branches/ plant	Plant height (cm)	Ascorbic acid content (mg/100 g)	Marketable fruit yield/ plant (g)
1	PRC-1	7.62	2.90	2.84	2.93	4.00	45.90	82.43	687.59
2	California wonder	6.54	4.00	3.63	3.57	3.93	55.20	87.32	490.40
3	Rani Sel.1	8.32	3.20	2.90	3.01	4.60	49.00	66.68	700.84
4	SSP	9.75	3.33	3.35	3.33	4.53	46.66	64.10	720.61
5	Se1.12-2-1	12.85	2.66	2.13	3.04	4.20	45.20	73.46	469.51
6	SP-316	13.39	3.05	2.73	3.78	4.00	50.26	91.52	433.95
7	California Wonder × PRC-1	9.91	3.14	2.75	3.38	3.71	52.45	50.28	675.77
8	California Wonder × SSP	12.98	3.20	3.86	4.53	4.13	47.60	93.12	1180.13
9	California Wonder × Sel-12-2-1	11.67	2.83	2.36	2.91	3.56	53.65	71.13	557.10
10	PRC-1 × California Wonder	14.55	3.10	3.06	1.97	4.23	57.60	120.18	933.05
11	PRC-1 × Rani Sel-1	14.13	3.00	3.69	4.30	4.56	52.40	85.13	1370.06
12	PRC-1 × SSP	13.56	3.05	3.20	4.43	4.00	50.40	84.88	865.22
13	PRC-1 × Sel-12-2-1	9.75	3.23	3.29	3.40	3.73	48.90	88.53	995.76

Table 3. Contd.

14	PRC-1 × SP-316	9.41	2.95	2.40	4.40	4.46	44.40	91.46	644.26
15	Rani Sel-1 × SSP	11.35	3.11	3.40	4.00	4.66	47.20	101.69	809.92
16	Rani Sel-1 × Sel-12-2-1	11.79	3.26	3.63	3.55	3.96	58.90	105.89	1023.12
17	Rani Sel-1 × SP-316	10.96	3.46	2.96	3.06	3.60	51.66	46.63	581.92
18	SSP × Sel-12-2-1	14.18	2.86	3.60	3.96	4.60	45.40	73.61	830.06
19	SSP × SP-316	13.58	2.80	3.43	3.96	4.60	47.00	95.63	898.38
20	(Sel Sel-12-2-1 × SP-316	11.56	2.36	3.20	3.38	3.60	55.60	80.13	597.22
21	California Wonder × SP-316	16.76	3.13	2.96	4.76	4.20	52.40	69.57	631.53
	SE±	1.57	0.27	0.35	0.37	0.32	0.75	6.24	36.12
	CD at 1%	3.17	0.56	0.71	0.76	0.66	2.02	12.61	73.00
	CD at 5%	4.24	0.75	0.95	1.02	0.89	1.51	16.87	97.67

cross combinations California Wonder × SP-316 (156.61%), PRC-1 × California Wonder (121.99%) and California Wonder × SSP (98.57%) had exhibited the significant highest positive heterobeltiosis, respectively. Only ten F1 crosses could reveal significant positive heterobeltiosis over better parent. Out of fifteen, fourteen F1 crosses exhibited significant positive heterosis except PRC-1 × SP-316 over the standard check, respectively. The highest economic heterosis was exhibited by the hybrid California Wonder × SP-316 to the tune of 155.98%. The top three hybrids for number of fruits per plant over better parent were California Wonder × SP-316 (156.61%), PRC-1 × California Wonder (121.99%) and California Wonder × SSP (98.57%) and SP-316 × California Wonder (155.98%), PRC-1 × Rani Sel-1 (155.82%) and California Wonder × SSP (98.27%) over standard check. The perusal of data of plant height revealed that the magnitudes of heterosis were ranged from -3.26 to 30.30 and -2.80 to 6.70% over better parent and standard check, respectively. Only one F1 cross PRC-1 × SP-316 (-3.26%) was found with significant negative heterosis for plant height over superior parent. Among 15 F1 crosses, twelve were found with significant negative heterosis over standard check. The highest desirable economic heterosis was recorded in cross combination Rani Sel-1 × Sel-12-2-1 (6.70%) over standard check for plant height.

The magnitudes of heterosis for number of lobes were ranged from 18.65 to 117.91% over better parent and -46.45 to -21.56% over standard check, respectively. All the fifteen crosses were found with positive significant heterosis for number of lobes per fruit over superior parent. The cross combination Rani sel-1 × Sel-12-2-1 (117.91) followed by PRC-1 × Sel-12-2-1 (112.09) had exhibited highest significant positive heterobeltiosis. None of the crosses was found with significant positive heterosis over standard check. The highest negative heterosis was recorded in cross combination Rani Sel-1 × SP-316 (-21.56%) over standard check. The top three hybrids for number of lobes over better parent were Rani Sel-1 × Sel-12-2-1 (117.91%), PRC-1 × Sel-12-2-1 (112.09%) and SSP × SP-316 (107.02%), respectively. The magnitude of heterosis was ranged from -4.09 to 22.50% and -34.80 to 6.42% over the better parent and standard check, respectively. Only four F1 crosses were found with positive significant heterosis for pedicel length over superior parent. The F1 crosses Rani Sel-1 × Sel-12-2-1 (22.50%) followed by PRC-1 × Sel-12-2-1 (21.25%) had exhibited the highest significant positive heterobeltiosis. Among 15 F1 crosses, none of the cross was found with significant positive heterosis over standard check. The top ranking three hybrids for pedicel length over better parent were Rani Sel-1 × Sel-12-2-1 (22.50%), PRC-1 × Sel-12-2-1 (21.25%) and Sel-12-2-1 × SP-316 (11.25%).

The magnitudes of heterosis for pericarp thickness were ranged from -15.59 to 70.31 and -44.72 to 33.52% over better parent and standard check, respectively. Out of fifteen, only five F1 crosses were found with positive significant heterosis for pericarp thickness over superior parent. The cross combination Rani Sel-1 × Sel-12-2-1 (70.31%) followed by SSP × Sel-12-2-1 (68.75%) had exhibited the highest significant positive heterobeltiosis. As many as four crosses were found with significant positive heterosis over standard check. The highest economic heterosis was recorded in cross combination California Wonder × SP-316 (33.52%) over standard check. The top three hybrids for pericarp thickness over better parent were Rani Sel-1 × Sel-12-2-1 (70.31%), and PRC-1 × Sel-12-2-1 (54.53%), and

Table 4. Estimation of Heterosis in F_1 crosses of bell pepper for different horticulture traits.

Cross	P1 × P2	P1 × P3	P1 × P4	P1 × P5	P1 × P6	P2 × P3	P2 × P4	P2 × P5	P2 × P6	P3 × P4	P3 × P5	P3 × P6	P4 × P5	P4 × P6	P5 × P6
1a	-7.36**	-4.03*	-7.48**	4.84**	-9.56**	5.83**	-12.86**	-6.22**	-9.67**	-6.72**	-0.84	-4.56**	-10.74**	-8.57**	2.04
1b	-13.33**	-10.83**	-12.50**	-0.83	-13.33**	5.83**	-12.50**	-5.83**	-6.66**	-7.50**	-1.66	-4.16**	-10.00**	-6.66**	4.16*
2a	-7.36**	-4.03*	-7.48**	4.84**	-9.56**	-11.87**	-3.01	-6.27**	-9.67**	1.90	-10.77**	-2.69	-9.48**	-13.00**	2.15
2b	-13.33**	-10.83**	-12.50**	-0.83	-13.33**	-11.87**	2.74	-4.56**	-6.66**	-2.28	-5.47**	-0.91	-4.11*	11.41*	8.21**
3a	22.63*	44.44**	21.05*	26.31*	0.00	10.52	-5.00	-8.50	-20.00*	5.55	27.22*	41.66**	0.43	5.00	-3.50
3b	29.93**	24.93**	14.94	14.94	15.04	4.94	-5.04	-8.79	20.04*	14.94	10.79	31.43**	9.94	-0.05	-8.49
4a	16.33**	35.07**	-1.16	97.94**	11.77*	5.94	39.41**	31.49**	-20.96**	-2.10	102.73**	2.76	83.58**	48.18**	15.57*
4b	16.34**	49.50**	9.41*	31.31**	-2.96	5.94	39.42**	-12.76**	-31.38**	12.19**	34.49**	-10.78*	21.78**	28.64**	-23.32**
5a	-2.46	9.97*	8.20*	28.58**	-5.63	-7.82	14.87**	2.35	5.43	3.39	30.64**	-5.24	22.38**	9.76*	-2.63
5b	-2.52	16.12**	14.26**	8.54*	-13.35**	-7.88	14.80**	-13.59**	-3.18	9.92*	10.28*	-12.99**	3.30	0.78	17.81*
6a	11.25**	11.55*	1.51	27.03**	31.39**	18.79**	9.62	34.17**	-3.96	9.17	24.51**	5.56	32.54**	40.76**	36.74**
6b	11.21**	29.51**	16.24*	10.22	52.54**	18.75**	9.59	16.41*	-3.99	25.01**	8.03	24.77**	15.00*	61.18**	18.64**
7a	-1.61	15.78**	-4.11	24.28**	4.80	-4.43	11.21*	5.07	-8.74	16.78**	21.90**	1.04	25.71**	5.28	13.13*
7b	-1.59	16.55**	-1.57	8.57	1.43	-4.41	11.24*	-8.20	-11.66*	17.56**	6.49	-2.19	9.82*	1.90	-1.16
8a	121.99**	85.75**	77.88**	28.05	23.25	51.68*	98.57**	78.20**	156.61**	36.56	42.17*	31.59	45.24**	39.10*	-10.10
8b	122.18**	155.82**	107.02**	48.90*	43.76	51.34*	98.27**	78.21**	155.98**	73.33**	80.05**	67.43**	116.48**	107.37**	76.59**
9a	25.49*	14.16*	12.85*	8.18*	-3.26*	4.50*	6.58*	19.14*	4.25*	5.68*	30.30*	5.42*	1.65	5.23*	2.21
9b	4.34*	-5.07*	-8.69*	-13.04*	-19.56*	-5.00*	-13.76*	-2.80*	-5.07*	-14.49*	6.70*	-6.41*	-17.75*	-14.85*	-16.30*
10a	90.26**	99.25**	25.83**	112.09**	48.46**	37.79**	104.64**	18.65**	45.52**	15.56**	117.91**	34.09**	76.79**	107.02**	37.62**
10b	-29.86**	-32.12**	-30.99**	- 26.84**	-33.25**	-28.88**	-27.60**	-35.89**	-29.11**	-29.48**	-26.09**	-21.56**	-35.14**	-36.65**	- 46.45**
11a	6.89	3.44	5.17	21.25*	1.72	8.39	-4.09	6.25	2.73	-2.60	22.50*	13.66	7.50	*8.19	*11.25
11b	-15.51	1.83	-11.84	-9.18	-33.88**	-24.24*	6.42	-34.80**	-18.27	-6.33	0.09	-18.27	-0.82	-5.41	11.84
12a	7.85	30.01*	12.54	54.53**	-15.59	-3.28	15.20	10.93	3.48	17.24	70.31**	3.48	68.75**	19.76	50.00**
12b	-44.72**	20.54	24.18*	-4.66	23.24*	-5.22	26.98*	-18.39	33.52**	12.04	-0.46	-14.09	11.11	11.11	-5.13
13a	-32.72*	46.70**	51.13**	16.02	50.00**	15.34	36.00**	-4.37	33.39**	32.89*	18.05	1.88	30.19*	19.00	11.16
13b	7.71	16.20	1.78	-5.08	13.65	-5.42	5.17	-9.24	6.87	18.74*	0.76	-8.39	17.04*	17.04*	-8.39
14a	-1.11	30.89*	20.36**	3.04	-1.85	-15.98	21.81**	-8.21	-2.36	8.59	10.99	-3.14	7.69	7.69	-10.27
14b	37.61**	-2.51	-2.79	1.37	4.73	-42.42**	6.63	-18.54*	-20.33**	16.44*	21.25**	-25.99**	-15.70*	9.51	-8.24
15a	45.81**	27.67**	32.42**	20.51*	10.95	-39.00**	45.27**	-3.17	-20.33**	58.63**	58.84**	-3.06	14.84	49.18**	9.07
15b	90.25**	170.37**	76.42**	103.05**	31.37**	37.79**	140.64**	13.59	28.77**	65.15**	108.62**	18.66*	69.25**	83.19**	21.78**

a = percent increase over better parent, b = percent increase over standard check (California Wonder) (1 to 15 horticultural traits).

California Wonder × SP-316 (33.52%), California Wonder × SSP (26.98%) and PRC-1 × SSP (24.18%) over standard check. The estimates of percent heterosis for number of branches per plant ranged from -4.37 to 51.13 and -9.24 to 18.74% over the superior parent and standard check, respectively. Seven F1 crosses had exhibited significant positive heterobeltiosis. The highest heterobeltiosis was recorded in

Table 5. Top three parents and cross combinations on the basis of their per se performance and heterotic values.

Traits	Per se performance		Heterosis	
	Parents	Crosses	BP	SC
Days to 50% flowering	PRC-1, Rani Sel-1, SSP	PRC-1 × California Wonder, PRC-1 × SP-316 (34.66), PRC-1 × SSP (35.00)	California Wonder × SSP (-12.86), SSP × Sel-12-2-1 (-10.74), California Wonder × SP-316 (-9.67)	PRC-1 × California Wonder (-13.33), PRC-1 × SP-316 (-13.33) California Wonder × SSP (-12.50)
Days to first harvest	PRC-1, Rani Sel-1 California Wonder	PRC-1 × SP-316 (62.33), California Wonder × SSP(64.33), PRC-1 × SSP (64.33)	PRC-1 × SP-316 (-16.14), SSP × SP-316 (-13.00), California Wonder × SSP (-11.87)	California Wonder × SSP (-11.87) PRC-1 × SSP (-11.87) PRC-1 × California Wonder (-10.04)
No. of pickings	SSP, Rani Sel-1, PRC-1	Rani Sel-1× SP-316 (8.76), PRC-1 × California Wonder (8.66), PRC-1 × Rani Sel-1(8.33)	PRC-1 × Rani Sel-1 (44.44), Rani Sel-1× SP316 (41.66), Rani Sel-1× Sel-12-2-1 (27.22)	Rani Sel-1 × SP-316 (31.43), PRC-1 × California Wonder (29.93) PRC-1 × Rani Sel-1 (24.93)
Fruit weight	SSP, Rani Sel-1, California Wonder	PRC-1 × Rani Sel-1(100.66), California Wonder × SSP(93.87), Rani Sel-1× Sel-12-2-1(90.55)	Rani Sel-1× Sel-12-2-1 (102.73), PRC-1 × Sel-12-2-1 (97.94), SSP × Sel-12-2-1 (83.58)	PRC-1 × Rani Sel-1 (49.50), California Wonder × Rani Sel-1 (39.41), Rani Sel-1× Sel-12-2-1 (34.49)
Fruit diameter	SSP, Rani Sel-1, PRC-1	California Wonder × SSP(6.36), PRC-1 × SSP (6.33), Rani Sel-1× Sel-12-2-1(6.11)	Rani Sel-1× Sel-12-2-1 (30.64), PRC-1 × Sel-12-2-1 (28.58) SSP × Sel-12-2-1 (22.38)	Sel-12-2-1× SP-316 (17.81), PRC-1 × Rani Sel-1 (16.12) California Wonder × SSP (14.80)
Fruit length	Rani Sel-1 SSP, PRC-1	SSP × SP-316 (15.18), PRC-1 × SP-316 (14.37), PRC-1 × Rani Sel-1(12.20)	SSP × SP-316 (40.76), Sel-12-2-1× SP-316 (36.74), California Wonder × Sel-12-2-1 (34.17)	SSP × SP-316 (61.18), PRC-1 × SP-316 (52.54), PRC-1 × Rani Sel-1 (29.51)
Fruit girth	SSP, Rani Sel-1 PRC-1	Rani Sel-1× SSP (20.15), PRC-1 × Rani Sel-1 (19.97), California Wonder × SSP (19.06)	SSP × Sel-12-2-1 (25.71), PRC-1 × Sel-12-2-1 (24.28), Rani Sel-1× Sel-12-2-1) (21.90)	Rani Sel-1× SSP (17.56), PRC-1 × Rani Sel-1 (16.55) California Wonder × SSP (11.21)
No. of fruit/ plant	SP-316, Sel-12-2-1, SSP	California Wonder × SP-316 (16.76) PRC-1 × California Wonder (14.55) SSP × Sel-12-2-1(14.18)	California Wonder × SP-316 (156.61), PRC-1 × California Wonder (121.99) California Wonder × SSP (98.57)	California Wonder × SP-316 (155.98) PRC-1 × Rani Sel-1 (155.82), PRC-1 × California Wonder (122.18)
No. of lobs/ fruit	California Wonder SSP, Rani Sel-1	Rani Sel-1× SP-316 (3.46), Rani Sel-1× Sel-12-2-1 (3.26), PRC-1 × Sel-12-2-1 (3.23)	Rani Sel-1× Sel-12-2-1 (117.91), PRC-1 × Sel-12-2-1 (112.09), SSP × SP-316 (107.02)	Rani Sel-1× SP-316 (-21.56), Rani Sel-1× Sel-12-2-1 (-26.09), PRC-1× Sel-12-2-1 (-26.84)

Table 5. Contd.

Pedicel length	CaliforniaWonder, SSP, Rani Sel-1	California Wonder × SSP (3.86), PRC-1 × Rani Sel-1 (3.69), Rani Sel-1× Sel-12-2-1 (3.63)	Rani Sel-1× Sel-12-2-1 (22.50), PRC-1 × Sel-12-2-1 (21.25), Rani Sel-1 × SP-316 (13.66)	California Wonder × SSP (6.42), Rani Sel-1× Sel-12-2-1 (0.092), SSP × Sel-12-2-1 (-0.826)
Pericarp thickness	SP-316, California Wonder, SSP	California Wonder × SP316 (4.76) Rani Sel-1× SSP (4.60), PRC-1 × SP-316 (4.40)	Rani Sel-1× Sel-12-2-1(70.31), SSP × Sel-12-2-1 (68.75), PRC-1 × Sel-12-2-1 (54.53)	California Wonder × SP316 (33.52), California Wonder × SSP (26.98), PRC-1 × SP316 (23.24)
No. of branches/plant	Rani Sel-1, SSP, Sel-12-2-1	Rani Sel-1× SSP (4.66), SSP × Sel-12-2-1 (4.60), SSP × SP-316 (4.60)	PRC-1 × SSP (51.13), PRC-1 × SP-316 (50.00), PRC-1 × Rani Sel-1 (46.70)	Rani Sel-1× SSP (18.74), SP × Sel-12-2-1 (17.04) SSP × SP-316 (17.04)
Plant height	Sel-12-2-1, PRC-1, SSP	PRC-1×SSP, PRC-1×SP-16 Rani Sel-1×SSP	PRC-1 × SSP	California Wonder × Sel-12-2-1 PRC-1 × Rani Sel California Wonder × SP-316
Ascorbic acid content	SP-316, California Wonder, PRC-1	PRC-1 × California Wonder (120.18), Rani Sel-1× Sel-12-2-1 (105.89), Rani Sel-1× SSP (101.69)	PRC-1 × Rani Sel-1 (30.89), California Wonder × SSP (21) PRC-1 × SSP (20.36)	PRC-1 × California Wonder (37.61), Rani Sel-1× Sel-12-2-1 (21.25), California Wonder × SSP (6.63)
Marketable fruit yield/plant	SSP, Rani Sel-1, PRC-1	PRC-1 × Rani Sel-1 (1370.06), California Wonder × SSP (1180.13), Rani Sel-1× Sel-12-2-1 (1023.12)	Rani Sel-1× SP-316 (58.84), Rani Sel-1× Sel-12-2-1 (58.63), SSP × SP-316 (49.18)	PRC-1 × Rani Sel-1 (170.37), California Wonder × SSP (140.64), Rani Sel-1 × Sel-12-2-1

PRC-1 × SSP (51.13%) followed by PRC-1 × SP316 (50.00%). On other side, the highest economic heterosis was recorded in cross Rani Sel-1 × SSP to the tune of 18.74% over standard check. The top three hybrids for number of branches per plant over better parent were PRC-1 × SSP (51.13%), PRC-1 × SP-316 (50.00%) and PRC-1 × Rani Sel-1 (46.70%) and Rani Sel-1 × SSP (18.74%), SSP × Sel-12-2-1 (17.04%) and SSP × SP-316 (17.04%) over standard check.

The magnitudes of heterosis for ascorbic acid content were ranged from -15.98 to 30.89 and -25.99 to 37.61% over better parent and standard check, respectively. Only three crosses were found with positive significant heterosis for ascorbic acid content in F1 generation over superior parent. The cross combination PRC-1 × Rani Sel-1 (30.89%) followed by California Wonder × SSP (21.81%) had exhibited the highest significant positive heterobeltiosis. Three crosses out of fifteen were found with significant positive heterosis over standard check. The highest economic heterosis to the extent of 37.61% was recorded in cross combination PRC-1 × California Wonder over standard check. The top three hybrids for ascorbic acid content over better parent were PRC-1 × Rani Sel-1 (30.89%), California Wonder × SSP (21.81%) and PRC-1 × SSP (20.36%) and PRC-1 × California Wonder (37.61%), Rani Sel-1 × Sel-12-2-1 (21.25%) and Rani Sel-1 × SSP (16.44%) over Standard check. The magnitudes of heterosis for marketable fruit yield per plant were ranged from -39.00 to 58.84% and -13.59 to 170.37% over better parent and standard check, respectively. Eight crosses were observed with positive significant heterosis for marketable fruit yield per plant in F1 generation over superior parent. The cross combination Rani Sel-1 × Sel-12-2-1 followed by Rani Sel-1 × SSP had manifested the highest significant positive heterobeltiosis to the tune of 58.84 and 58.63%, respectively. Out of fifteen F1 crosses, fourteen were found with significant positive heterosis over standard check. The highest economic heterosis was recorded in cross combination PRC-1 x Rani

Sel-1 to the tune of 170.37% over standard check followed by California Wonder × SSP (140.64%) and Rani Sel-1 × Sel-12-2-1 (108.62%), respectively.

The top ranking three hybrids for marketable yield over better parent were Rani Sel-1 × Sel-12-2-1 (58.84%), Rani Sel-1 × SSP (58.63%) and SSP × SP-316 (49.18%) and PRC-1 × Rani Sel-1 (170.37%), California Wonder × SSP (140.64%) and Rani Sel-1 × Sel-12-2-1 (108.62%) over standard check.

DISCUSSION

Heterosis is the increase of size, yield and vigor through cross-breeding rather than interbreeding; without increases, there is no heterosis. Heterosis has a slightly more extensive coverage than hybrid vigor; that is, though all hybrid vigor is heterosis, not all heterosis can be with equal propriety termed hybrid vigor. Heterosis breeding is a potential method to achieve improvement in production and productivity of bell pepper that otherwise cannot be achieved through existing traditional methods. Negative heterosis for days to 50% flowering is considered desirable for earliness. In the present study, twelve F_1 crosses exhibited significant negative heterosis for days to 50% flowering. The cross combination California Wonder × SSP (-12.76%) followed by SSP × Sel-12-2-1 (-10.72%) had revealed the highest heterobeltiosis for this trait. Sujiprihati et al. (2007) had also been reported desirable negative heterosis for days to 50% flowering. Heterosis for early fruit yield was manifested through negative desirable heterosis for days to first harvest. The F_1 crosses California Wonder × SSP and PRC-1 × SSP exhibited highest significant heterosis in desirable direction to the tune of - 11.87% each over standard check. The highest economic heterosis was recorded for number of fruit pickings in cross Rani Sel-1 × SP-316 to the tune of 31.43% over standard. Similar findings had also been reported by Prasad et al. (2003). Such cross could be utilized for hybrid breeding for production of fruits over a long time by increasing picking. The highest economic heterosis for fruit weight was recorded in cross combination PRC-1 × Rani Sel-1 (49.50%) over standard check.

Heterobeltiotic effects for fruit weight in bell pepper were earlier reported by Gomide et al. (2008). The top ranking hybrids for fruit diameter were Rani Sel-1 × Sel-12-2-1 (30.64%), PRC-1 × Sel-12-2-1 (28.58%) and SSP × Sel-12-2-1 (22.38%) over better parent and Sel-12-2-1 × SP-316 (17.81%), PRC-1 × Rani Sel-1 (16.12%) and California Wonder × SSP (14.80%) over standard check. Significant heterosis for fruit diameter was also reported earlier by Ahmed et al. (2003), Rajesh and Gulshan (2001) and Prasad et al. (2003). Significant positive highest magnitude of heterosis for fruit girth was recorded in SSP × Sel-12-2-1 (25.71%), PRC-1 × Sel-12-2-1 (24.28%), Rani Sel-1 × Sel-12-2-1 (21.90%) over the better parent. The maximum useful heterosis was exhibited by the cross combination SSP × Sel-12-2-1 to the tune of -8.74 to 25.71% over standard check. High value of heterosis favours the development of hybrid, which was in conformity with the findings of Bhagyalakshmi et al. (1991). The highest heterosis to the tune of 155.98% over standard parent was exhibited by the hybrid California Wonder × SP-316. Significant heterosis for number of fruit per plant had also been observed earlier by Joshi (1986). Among the traits, fruit per plant exhibited maximum heterosis over standard check 'Aishwarya' followed by marketable fruit per plant, harvest duration and fruit yield per plant by Sood and Kumar (2010b). Shrestha et al. (2011) were found hybrid of 5AVS7 × SP32 exhibited the highest heterosis for fruit number (104.0%) and yield (141.2%) per plant. Hybrids of 5AVS7 × SP45, 5AVS7 × SP32 and 5AVS8 × SP48 had highest positive standard heterosis on fruit yield per plant over Special, Fiesta and President.

The results, thus suggested that heterosis breeding may be utilized to exploit the non-additive components followed by selection in segregating generations. The parents SP-316 and Sel-12-2-1 could be utilized in future breeding programme to develop hybrids/pure lines having more number of fruits per plant. The F_1 cross Rani Sel-1 × Sel-12-2-1 (22.50%) followed by PRC-1 × Sel-12-2-1 (21.25%) had exhibited the highest significant positive heterobeltiosis. Significant heterosis for pedicel length had also been reported earlier by Ahmed et al. (2003) and Gomide et al. (2008). The F_1 crosses PRC-1 × SP-316 (-3.26%) had exhibited the highest significant positive heterobeltiosis for plant height. Similar finding were also reported earlier by Ahmed et al. (2003) and Rajesh and Gulshan (2001). Significant heterosis was found over better parent in the cross Sel-1 × Sel-12-2-1 (117.91%), PRC-1 × Sel-12-2-1 (112.09%) and SSP × SP-316 (107.02%). Similar results were also obtained earlier by Sujiprihati et al. (2007). The highest economic heterosis for number of branches was recorded in cross Rani Sel-1 × SSP to the tune of 18.74% over standard check. The significant heterosis for number of branches had over better parent and standard check also been reported earlier by Joshi (1986) and Sujiprihati et al. (2007). The highest useful heterosis for the trait had exhibited by PRC-1 × California Wonder to the tune of 37.61% over standard check. Similar findings for ascorbic acid were also reported by Vandana et al. (2002) and Gomide et al. (2008).

The highest economic heterosis for fruit yield per plant was recorded in cross combination PRC-1 × Rani Sel-1 to the tune of 170.37% over standard check followed by California Wonder × SSP (140.64%) and Rani Sel-1 × Sel-12-2-1 (108.62%), respectively. Significant desirable heterosis for fruit yield per plant was also reported earlier by Zecevic (1997), Ahmed et al. (2003), Milerue and Nikornpun (2006) and Sujiprihati et al. (2007). On the basis of heterosis and per se performance, PRC-1 × Rani

Sel-1 was the best cross-combination followed by California Wonder × SSP and Rani Sel-1 × Sel-12-2-1 for fruit yield per plant (Table 5). These cross combinations also had high heterosis for most of the yield contributing traits. These hybrids offer high scope for the exploitation of heterosis for improving horticultural traits. These cross-combinations could be utilized as hybrid breeding and can also be released as hybrids after further field testing.

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